

Sodium Adsorption Ratio-Exchangeable Sodium Percentage Relationships in a High Potassium Saline-Sodic Soil

Charles W. Robbins

Snake River Conservation Research Center, USDA-ARS, Route 1, Box 186, Kimberly, ID 83341, USA

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Summary. Exchangeable sodium percentage (ESP) and sodium absorption ratio (SAR) values were obtained from 692 soil samples and their saturation extract solutions. All samples were from a Declo silt loam (coarse, loamy, mixed, mesic, Xerollic Calciorrhids) phase that was saline-sodic and very high in potassium (K). Some samples contained as much as 80 meq K/l in the saturation paste extract. In those samples where the Na:K ratio was less than 4:1 the measured ESP was considerably lower at a given SAR than is usually observed in high Na soils. As the soluble salts were leached from this soil in lysimeters and under field conditions, with or without Ca amendments, the soil did not become sodic nor have decreased infiltration rates when irrigated with low salt water (200 $\mu\text{mhos/cm}$). The exchangeable K was more tightly held on the exchange sites than were Ca, Mg, or Na, thus reducing the high Na effects.

The sodium absorption ratio (SAR) of soil solution extracts, irrigation waters and subsurface drainage waters has been an important tool for predicting the equilibrium exchangeable sodium percentage (ESP) in salt affected soils. The degree of sodium hazard in the soil has then been related to the soil ESP (U.S. Salinity Laboratory Staff, 1954). SAR is usually defined as:

$$\text{SAR} = \text{NA} \left(\frac{\text{Ca} + \text{Mg}}{2} \right)^{-1/2} = [\text{Na}] ([\text{Ca}] + [\text{Mg}])^{-1/2} \quad (1)$$

where the unbracketed cation concentrations are in meq/l and the bracketed cation concentrations are in mmol/l units. If total cation concentrations are used, Sposito and Mattigod (1977) refer to the results as practical SAR or SAR_p . In an attempt to account for non-ideal solution-ion interactions, Oster and Sposito (1980) have defined SAR^* as:

$$\text{SAR}^* = (\text{Na}) (\text{Ca})^{-1/2} = 0.08 + 1.115 \text{ SAR}_p \quad (2)$$

where (Na) and (Ca) are the free-ion molar concentrations corrected for ion pairing and ionic strength in natural systems rather than total molar concentra-

tions. Cation concentrations have usually been used to calculate SAR, however, some investigators have used cation activities and others have used "free-ionic concentration" without always defining what corrections have been made. The above definitions either assume that Ca and Mg react alike with respect to Na exchange (1) or that Mg is not involved in the exchange reactions (2). Both SAR calculations ignore other soluble cations such as potassium (K).

The ESP is usually defined as

$$\text{ESP} = 100 \times \frac{\text{Exchangeable Na}}{\text{CEC}} \quad (3)$$

where CEC is the cation exchange capacity or calculated from the total exchangeable cations. The CEC and the exchangeable Na have traditionally been expressed in meq/100 g soil.

The relationship between SAR and ESP has been used in expressions ranging in complexity from $\text{ESP} = \text{SAR}$ (Jury et al. 1979), which does not allow SAR to exceed 100, through a series of expressions discussed by Oster and Sposito (1980), to the empirical relationship;

$$\text{ESP} = \frac{100(-0.0126 + 0.01475 \text{ SAR})}{1 + (-0.0126 + 0.01475 \text{ SAR})} \quad (4)$$

as developed from statistical analysis of many soil sample data (U.S. Salinity Laboratory Staff, 1954). Sposito and Mattigod (1977) suggest that an exact relationship between SAR and ESP does not exist.

Agricultural soils in Idaho used for irrigation disposal of sugar beet processing plant waste water have received as much as 3,400 kg K/ha per year (Smith and Hayden 1981). Several soils being irrigated with potato processing plant waste water have received over 2,500 kg K/ha per year with one site receiving over 5,000 kg K/ha per year (Smith et al. 1978). Likewise there are soils such as Blackrock gravelly loam (fine loamy, mixed, mesic, Cumulic Haploxerolls) located in northern Utah, in which 80% of the exchangeable cations are K (Southard and Kolesar 1978) and Declo sandy loam (coarse-loamy, mixed, mesic, Xerollic Calciorthis) in southern Idaho that contains as much as 80 meq K/l in the saturation extracts. The Declo soil has saline-sodic phases, but in the high K areas it does not seal up when irrigated with very low salt water as do many saline-sodic soils (Robbins and Carter 1983). When Reeve et al. (1954) treated 8 soils with Na and K they found that the permeability ratio and modulus of rupture increased significantly with increased exchangeable sodium percentage while exchangeable potassium percentages had little effect on these parameters. When 1,120 to 11,200 kg K/ha was added to two Saskatchewan dryland farm soils, the K replaced Ca and Mg in the surface 0.15 m and for the most part did not leach below 0.15 m in five years. The replaced Ca and Mg was leached from the zone of exchange (Ballantyne 1974). Previous work with eight salt affected and calcareous soils showed that K is more tightly held than Ca, Mg, and Na which are the cations usually considered when diagnosing and treating saline and alkali soils (Robbins and Carter 1983). There are only limited data available on high K applications to soils and on the leaching of high K salts from salt affected soils.

The purpose of this paper is to evaluate the effects of high K on SAR-ESP relationships and the response of a high K saline-alkali soil to chemical amendment and irrigation with low salt water.

Methods and Materials

Data from 692 soil samples taken from a field study, a lysimeter study, and samples from fields near the field study site which had shown saline and poor infiltration symptoms, were used for this study. All soil samples were from Declo silt loam (coarse-loamy, mixed, mesic, Xerollic Calciorthids). This soil contains illite and poorly crystalline expandable clay material and has a cation exchange capacity ranging from 22 to 26 meq/100 g (Robbins and Carter 1983).

The native vegetation, primarily greasewood (*Sarcobatus vermiculatus*), was removed from the plot area in the fall of 1979. The three field study treatments were a check, 28 mt/ha CaCl_2 and 44 mt/ha $\text{CaSO}_4 \cdot 2 \text{H}_2\text{O}$ replicated 3 times in a completely randomized design. These treatments represent calcium (Ca) applications equal to the exchangeable sodium to a depth of 0.5 m. These treatments were applied in November 1979, and then the plot area was plowed and then sprinkle irrigated with 70 mm of water. The plots were planted to barley (*Hordeum vulgare* L. 'Steptoe') and alfalfa (*Medicago sativa* L. 'Ranger') in April 1980. The barley was harvested that fall and then two alfalfa cuttings were harvested in 1981, but because of lack of available irrigation water after mid-July due to an exceptionally dry year, the alfalfa died out and so the plots were replanted to barley in April, 1982. The irrigation water had an average electrical conductivity of 200 $\mu\text{mhos/cm}$ and a SAR of less than 1. Duplicate soil samples were taken from each plot in 0.25 m increments down to 1.0 m before the treatments were applied and again in the falls of 1980, 1981, and 1982.

Soils for the lysimeter study were taken from the 0.30 m surface of a high K saline-sodic area near the field site previously described. The instrumented lysimeters were 0.30 m in diameter and 1 m deep (Robbins and Willardson 1980). The treatments were CaCl_2 , $\text{CaSO}_4 \cdot 2 \text{H}_2\text{O}$, and $\frac{1}{2} \text{CaCl}_2 + \frac{1}{2} \text{CaSO}_4 \cdot 2 \text{H}_2\text{O}$, added at Ca rates equal to the exchangeable Na in the upper 0.5 m of soil. The lysimeters were planted to barley plus alfalfa with the alfalfa remaining after the barley matured and was removed. The lysimeters were irrigated at a $\frac{1}{3}$ leaching fraction until a total of 1,800 mm of water had been added. The soils in the lysimeters were then sampled by 0.10 m depth increments.

Additional samples were taken in two sites near the field plot area. The first site had been sprinkle irrigated during years when water was available. From this site samples were intentionally taken from salt affected areas with normal infiltration rates and from areas which had the typical slick surface with the dark surface organic coatings and extremely low infiltration rates usually associated with sodic soils. The second site was still covered by native vegetation, primarily greasewood, and the soil was generally high in total soluble salts. Samples from both areas were taken in 0.25 m increments to a depth of 1 m.

All soil samples were air dried, ground, and passed through a 2 mm sieve. Cation (Ca, Mg, Na, and K) and anion (Cl , SO_4 , HCO_3 and CO_3) concentrations

and electrical conductivity (EC) were measured in the saturation paste extracts. Exchangeable Na and K were extracted with normal ammonium acetate (pH=7.0) (Yaalon and Koyumdjisky 1968). Exchangeable Ca and Mg were extracted with normal sodium acetate (pH=8.2) (Bower 1955).

The samples were grouped according to the Na : K concentration ratio in the saturation extract solution. The exchangeable sodium percentage was then plotted by group as a function of the sodium adsorption ratio and compared to the empirical equation (4) developed by the U.S. Salinity Laboratory Staff (1954). The effects, with depth, of the lysimeter treatments on the SAR-ESP relationship were also plotted.

Results

Grouping the soil solution and exchangeable cation data for all soil samples by the Na : K concentration ratio in the soil solution showed a marked decrease in the ESP for a given SAR as the Na : K ratio decreased (Fig. 1 a-f). When the Na : K solution ratio was near 20 : 1 the ESP-SAR relationship was not significantly different from that predicted by eq. (4) (Fig. 1 a). As the ratio changed to near 10 : 1 Na:K (not shown) the data points were mostly below the eq. (4) line but not strikingly different from the 20:1 data. As the Na:K ratio dropped to near 4:1, 3:1, and 2 : 1 there was a strong decrease in the ESP for a given SAR (Figs. 1 b, 1 c, and 1 d). When the Na concentration was equal to or less than the K concentration in the soil solution the ESP value never exceeded 25 (Fig. 1 e and 1 f). The greater the K concentration in relation to the Na concentration in the soil solution, the lower the ESP for a given SAR.

The soil used in the lysimeter had an original SAR of 44, and ESP of 23 and a Na : K ratio of 3 : 1. After the leaching phase had been completed, the soil columns were sampled at 0-0.05, 0.05-0.15, 0.15-0.25, 0.25-0.37, 0.37-0.50, 0.50-0.75, and 0.75-1.0 m increments, and are respectively designated as a through g in Fig. 2. As the treated soils were leached the Na : K ratio in the leachate water and water samples extracted from the various depths decreased only slightly below the original 3 : 1 value. The CaCl_2 treated soil was the most rapidly reclaimed, the $\text{CaCl}_2 + \text{CaSO}_4 \cdot 2 \text{H}_2\text{O}$ was intermediate and the $\text{CaSO}_4 \cdot 2 \text{H}_2\text{O}$ was the slowest. The surface or (a) depths had the most water and Ca pass through them and thus the greatest exchange of Ca for Na and Na leaching. The combination of less water and Ca passing through the lower (g) sample depth caused the least amount of reclamation. Each point is the mean of three samples, one from each lysimeter. For all depths and treatments SAR-ESP relationships fell near the line one would expect in a 3 : 1, Na : K ratio soil solution system from Fig. 1 c.

The same general reclamation patterns were observed in the field as in the lysimeters. The Na : K ratios did not change significantly for the four sampling dates for a given depth and plot over the three-year period. There was a greater variation in the Na : K ratio between plots of a particular treatment, depths within a given plot, and between duplicate samples within a plot depth than in the lysimeters. However, the Na : K ratio only decreased slightly with time for a given plot and depth, thus maintaining the unusual SAR-ESP relationship observed in

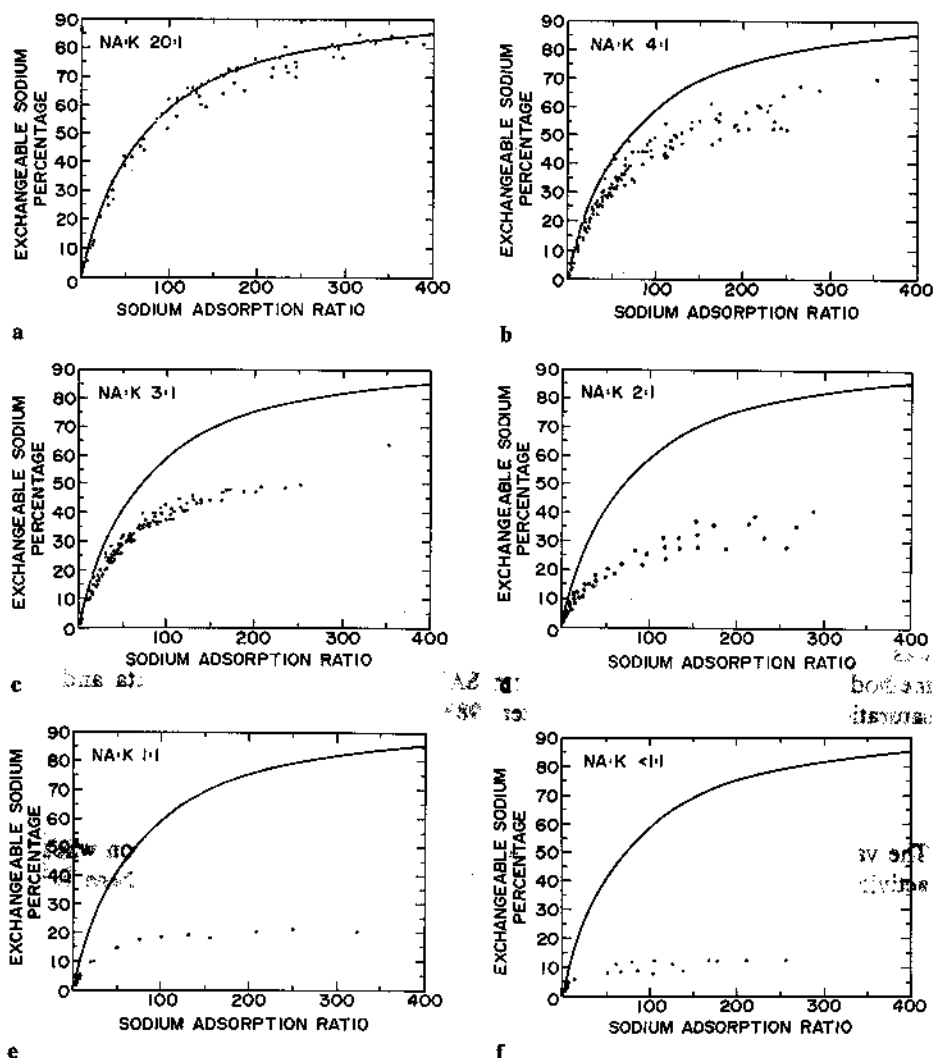


Fig. 1a-f. ESP-SAR relationship as affected by the Na:K ratio compared to that normally observed in salt affected soils. The solid line is from (4)

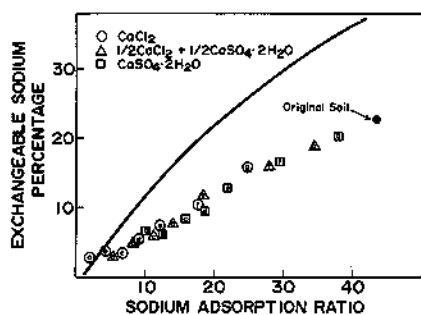


Fig. 2. ESP and SAR changes with calcium amendment treatment, leaching and depth where (a) represents the upper sampling increment and (g) is the bottom sampling increment. Equation (4) is represented by the solid line

the lysimeter samples. As the plot areas, including the checks and the non-treated border areas were irrigated with the low EC water ($EC = 200 \mu\text{mhos}$), and the excess salts were leached out, the areas with the low Na : K ratio did not disperse and show the typical sodic characteristic that is generally predicted when saline-sodic soils are leached with low salt irrigation water. After three irrigation seasons there were no measurable yield or visual infiltration differences between the checks, CaCl_2 , or $\text{CaSO}_4 \cdot 2 \text{H}_2\text{O}$ treated plots and the infiltration rates remained high enough for good plant growth.

Discussion

Potassium is less easily exchanged from many calcareous soils than is Ca, Mg, and Na (Robbins and Carter 1983). In Declo sandy loam, the soil used in this study, the selectivity for K-Ca exchange was found in previous work to be 1.9 ± 0.5 , for K-Mg exchange it was 7.7 ± 0.3 , and for K-Na exchange it was 7.7 ± 1.0 . This preference for K over the other three major cations in this soil with high soluble and exchangeable K explains the deviation of the SAR-ESP relationship, from that found in most sodium affected soils. The soil's preference for K over the other cations did not allow the ESP to be as high for a given SAR when the Na : K ratio was less than 4. Notwithstanding this difference in high K soils, there is a simple method for estimating the equilibrium SAR from irrigation water data and soil saturation extracts (Robbins and Carter 1983) by using

$$\text{ESP} = 100 \text{ Na} \left[(\text{Na}) + K_1 (\text{Ca})^{0.5} + K_2 (\text{Mg})^{0.5} + K_3 (\text{K}) \right]^{-1} \quad (5)$$

The values for K_1 , K_2 , and K_3 will vary with the soils and will depend on whether activities or concentrations are used for the cations. For the Declo soil these values were 4.0 ± 0.8 , 0.6 ± 0.1 , and 7.7 ± 1.0 when cation activities were used and were 2.0 ± 0.8 , 0.3 ± 0.2 , and 8.1 ± 1.1 , when cation concentrations were used. Using activities is the preferred method.

Observations on this high K soil indicate that where the Na : K ratio in the soil solution is 4 : 1 or less, these soils do not have lowered infiltration rates when irrigated and leached with low salt water. At the same time the ESP in these soils were lower than would be predicted from the soil solution SAR.

On the basis of these observations one would not expect irrigation with high K waste waters to have a serious detrimental effect on soil physical properties on these soils. Reeve et al. (1954) came to the same conclusions in their study with high exchangeable potassium ratio studies.

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